Transportation Research Part A 109 (2018) 76–88

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

Reducing Australian motor vehicle greenhouse gas emissions

John Stanley[a,*], Richard Ellison[a], Chris Loader[b], David Hensher[a]

[a] Institute of Transport and Logistics Studies, The University of Sydney Business School, NSW 2006, Australia
[b] Public Transport Research Group, Monash University, Clayton, Vic. 3800, Australia

ARTICLE INFO

Keywords:
Climate change
Fuel tax
Greenhouse gas emissions
Emissions intensity
Travel behaviour change
Vehicle kilometres travel

Classification codes:
R41
R42
R48

ABSTRACT

Australians are one of the world's highest per capita emitters of greenhouse gases, yet the country's target for emissions reductions by 2030 remains modest. This paper looks at policy options for Australian cities to deliver faster emissions reductions than the national commitment level. The main focus is on an accelerated reduction in emissions from urban road transport, through technological improvements and behaviour changes. Targets are proposed for improved emissions intensities, to bring Australia much closer to US and EU performance expectations. A range of behaviour change measures is then tested on Melbourne and Sydney, the Sydney analysis using MetroScan-TI, an integrated evaluation framework, to explore how behaviour changes might enhance emissions outcomes. The potential contribution of public transport is a particular focus. The paper concludes that, with sufficient political will, Australia could reduce its 2030 road transport emissions to 40% below 2005 levels. This is a much larger reduction than the current 26–28% Australian target but is more consistent with longer term pathways to acceptable carbon budgets.

1. Context: the challenge

The 2015 UN Paris Climate Change Conference (COP 21) confirmed a target of keeping the global rise in temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit these increases to 1.5 °C. It saw 186 countries committing to reducing their national greenhouse gas (GHG) emissions towards this end. The total of those commitments was, however, still seen as being associated with global warming of 2.6–3.1 °C, well above the target (Rogelj et al., 2016).

Australia is one of the world's highest per capita emitters of GHG (Union of Concerned Scientists, nd), typically only exceeded by a small number of oil producing states. Australia's Paris commitment to lower its GHG emissions by 26–28% on 2005 levels by 2030 was well below commitments made be a range of other countries, as illustrated in Fig. 1. From a longer term perspective, we have previously argued that high emitting countries like Australia should be aiming for greenhouse gas emission reductions by 2050 of at least 80% (on 2000 levels), well above the current national target (of 60% reduction) (Stanley et al., 2011).

The scale of Australia's 2030 commitment has been seriously challenged by two members of the Australian Government's Climate Change Authority. Hamilton and Karoly (2016) argue that, based on the Authority's 2014 recommended Australian carbon budget of 10.1 $GtCO^2$-e for the period 2013–50, a 26–28% reduction by 2030 places an excessive burden on emissions reduction beyond 2030, to the point where Australia would need to reach net zero emissions by 2035. To ease this transition path, they recommend that the Australian 2030 target should be a reduction of 40–60% on 2005 levels, not 26–28%.

The primary purpose of the present paper is to assess the prospects for achieving a GHG emissions reduction outcome at the

* Corresponding author.
E-mail addresses: john.stanley@sydney.edu.au (J. Stanley), richard.ellison@sydney.edu.au (R. Ellison), chris@cloader.net (C. Loader), david.hensher@sydney.edu.au (D. Hensher).

https://doi.org/10.1016/j.tra.2018.01.002
Received 11 July 2017; Received in revised form 1 November 2017; Accepted 3 January 2018
Available online 07 February 2018
0965-8564/

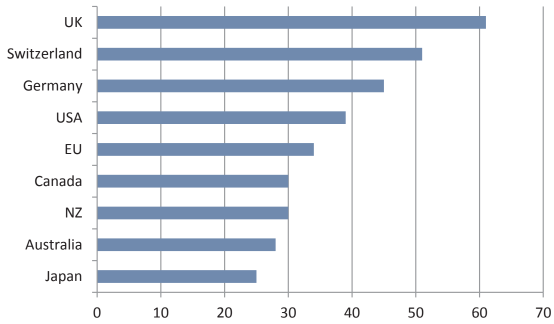

Fig. 1. GHG reduction committed by 2030, on 2005 levels (%)*. Note: *Where a country has nominated a range (e.g.,Australia and the US), the top of the range is shown.
Source: http://climatechangeauthority.gov.au/comparing-countries-emissions-targets.

bottom end of the 40–60% range for Australia's road transport sector by 2030, recognising that it is often thought that achieving transport emissions reductions is more difficult than achieving reductions from stationary energy sources. The paper summarises progress in Australia's efforts to reduce road transport GHG emissions. It then identifies the broad magnitude of changes that would be required if road transport was to make a proportionate contribution to a national reduction target of 40 + % by 2030, from a 2005 base, and assesses the feasibility of such changes, using some modelling applications.

Estimating future road transport GHG emissions requires, inter alia, assumptions about changes over time in

1. vehicle emissions intensities and
2. vehicle use (vehicle kilometres of travel or VKT).

These are, respectively, primarily about technological change and behaviour change, an organising framework that is used in the paper.

The paper is organised as follows. Section 2 discusses the general approach taken to develop a pathway for lower road transport GHG emissions, noting a number of similar approaches that have been taken for other countries or cities. Section 3 reviews trends in Australian road transport GHG emissions and in vehicle use. Section 4 looks at emissions intensities and asks whether reductions of 40 + % might be achievable between 2005 and 2030. Sections 5–7 then look at the question of vehicle use. A range of policy outcome areas are identified in Section 5 as potentially significant contributors to reducing growth in vehicle use, consistent with achievement of an overall reduction of road transport GHG emissions of around 40% by 2030. Sections 6 and 7 explore growth in VKT in Melbourne and Sydney respectively, these being Australia's two largest cities, and ways in which this growth might be slowed in coming years. Section 8 sets out the conclusions of the paper.

2. Approach

The research reported in this paper uses a scenario-based approach, similar to the approach taken in our earlier paper (Stanley et al., 2011) and to backcasting exercises undertaken by, for example, Åkerman and Höjer (2005) for Sweden, Hickman et al. (2010) for the UK and Hickman et al. (2014) for Auckland in New Zealand. Each of those applications identified the transport sector as lagging in terms of its contribution to GHG emission reductions and underlined the importance of both substantial technological change, to reduce emissions intensity, and behaviour change, to reduce VKT. We develop an aggregate scenario that is consistent with Australia meeting a 40% road transport GHG reduction target by 2030, against a 2005 base, and then consider the feasibility of delivering the various components of that scenario. Stanley et al. (2011) demonstrated that improvements in emissions intensity would need to make the major contribution to emissions reduction. Failure to achieve this, we showed, places demands on behaviour change that are almost certainly infeasible in terms of reaching aggregate target emissions reductions. Our scenario was thus developed with emissions intensity as the major contributor, as most similar studies agree (e.g., Hickman et al., 2010, 2014). European and US emission standards form the basis for our scenario in that regard, Australia not having mandatory standards. Having such a large part of the developed world with mandated standards in place makes the political task of achieving commitment in Australia more likely, in our view (one of us having been involved in these processes in a past life).

Behavioural components in our scenario draw on cities that we regard as best practice and having similar spatial and socio-demographic characteristics as Australian cities. Thus, for example, while we applaud, and envy, the cycling mode shares achieved in cities like Copenhagen, Amsterdam and Freiburg, these cities have little in common with Sydney and Melbourne. As Hickman et al. (2014) show, Western European cities generally have much higher densities, much lower rates of car ownership and much lower parking space availability than cities in Australia and New Zealand. One result is that European cities typically have per capita public transport boarding rates several times higher than their Australian counterparts. Cities like Vancouver and Portland (Oregon) are, we believe, more relevant for what might be achievable in terms of Australian behaviour change, with the European model cities as longer term guiding lights.

The scenario we assess is obviously not the only one that might achieve a 40% cut in Australian road transport GHG emissions by

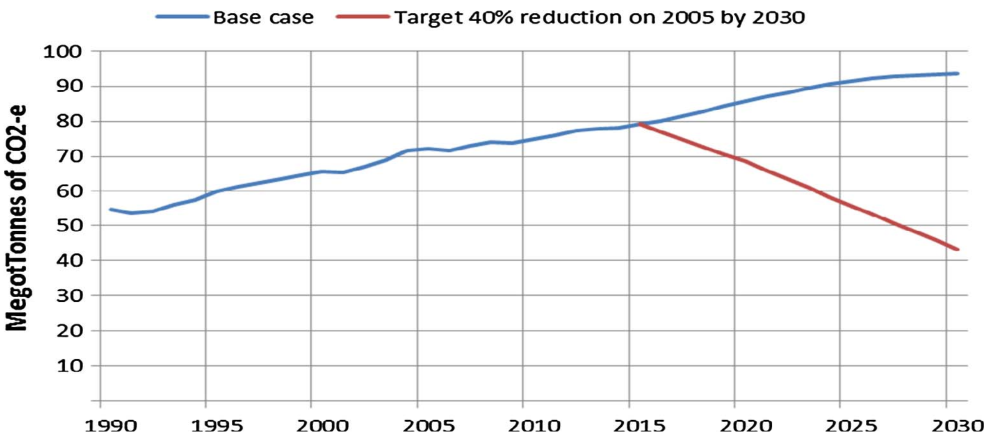

Fig. 2. Australian road transport GHG emissions: dimensioning a 40% cut on 2005 by 2030.
Source: Base case is from the Bureau of Infrastructure Transport and Regional Economics (BITRE) unpublished data; target is the authors' projection.

2030. However, it is reflective of a feasible pathway, which might form a realistic basis for a community and political conversation about change.

The modelling discussed in Sections 6 and 7, which supports development of this pathway, uses two different approaches. A key contribution of the paper is the application of a new urban land use transport modelling system (MetroScan), which enables analysis of detailed policy interventions that might be implemented to achieve accelerated emissions reductions. That model is used for our Sydney analysis in Section 7 but has not yet been estimated for Melbourne. The Section 6 Melbourne modelling, therefore, uses a more conventional transport modelling approach.

3. Australia: still climbing the road transport GHG emissions ladder

Australian transport sector GHG emissions in 2015 were 94.8 Mt CO_2-e and have grown by 55% since 1990, with the sector's share of Australian emissions increasing from 15% in 2002 to over 17% in 2015 (DEE 2017).[1] These data suggest that the transport sector is acting as a drag on national emissions reductions performance.

Road transport represents 84% of transport sector GHG emissions and must play a lead role in sector emissions reduction. Road transport GHG emissions were 72.6 Mt in 2005, increasing to 80.8 Mt in 2015 (DEE, n.d.). A business-as-usual (BAU) projection of road transport emissions in Fig. 2 suggests emissions of around 93.6 Mt in 2030. DOE (2015) projects continued growth in Australian road transport GHG emissions, fuelled by growth in passenger vehicles and continuation of low oil prices, but argues that 'finalisation of fuel efficiency standards will likely lead to a significant downward revision in the emissions outlook for this sector' (DOE 2015, p. 6). A 40% reduction on 2005 road transport emissions by 2030 requires sector emissions to be down to 43.3 Mt in 2030, implying cuts of 50 Mt against the 2030 base case (BAU) projection set out in Fig. 2.

Total vehicle kilometres across all Australian vehicle types and areas increased by 12.4% over the decade to 2015 (BITRE, 2016). Metropolitan car use is the dominant source of VKT, accounting for 43.5% in 2015 (excluding motor cycles). Growth of urban private vehicle use between 2005 and 2015 was under 0.7% p.a. in metro areas and under 0.5% p.a. in non-metro areas, a useful contributor to the relatively slow growth in GHG emissions from this category of vehicle over the decade. Light commercial vehicles (LCVs) account for a further 20% of motorised VKT, use growing much faster between 2005 and 2015 than car VKT, at around 3.2% p.a. on average over the decade. Articulated trucks account for 3.3% of motor vehicle VKT, with the lion's share (about 80%) being in non-metro use. VKTs were estimated to grow by about 2.4% p.a. over the decade. Rigid and other trucks (4% of VKT) and buses (1% of VKT) round out the total. The high growth rates in LCVs and larger trucks, in particular, are bad news for GHG emissions performance, given the higher emissions intensities of these vehicles.

The evidence thus strongly suggests that reducing motor vehicle VKT, to support a policy intent of reducing road transport GHG emissions, needs to focus on all vehicle types: cars because they are the dominant source of VKTs (and of total road transport GHG emissions); and LCVs, trucks (articulated and rigid) and buses, because their VKT numbers are growing more quickly than cars and they are more emission intensive than cars.

4. Emissions intensity outcomes to 2015 and a target for 2030

4.1. New passenger vehicles and LCVs

In terms of emissions reductions emanating from technological changes and changes in fleet mix, Australian new light vehicle

[1] Note that the above numbers do not include electric rail emissions, indirect emissions, or emissions from international shipping and aviation.

average emissions intensity has improved at an annual average linear rate of about 5.5 g of CO_2 per kilometre (g/km) over the 2002–15 period (derived from data presented in NTC, 2016). If emissions intensities continued to fall at the same absolute linear rate, the fleet average emissions intensity for *new* passenger vehicles and LCVs would be ~100 g/km by 2030. Achieving a sustained rate of emissions reduction per vehicle kilometre, in absolute terms, will become increasingly harder as the absolute level of emission intensity is reduced. However, the present paper adopts this projection as a benchmark for cars and light commercial vehicles. This would represent an improvement of 59% from 2005 and 46% from 2015, suggesting that the passenger/light vehicles part of the road transport sector, at least, could possibly do a lot better than the 26–28% reduction promised by Australia in Paris, provided increases in VKT do not offset gains from improved emissions intensity and provided either new vehicles diffuse very quickly through the total vehicle fleet (unlikely) and/or, more likely, the 100 g/km emissions figure is reached well before 2030.

How feasible is an Australian GHG emissions target of around 100 g/km for new passenger vehicles and LCVs before 2030? In their recent detailed scenario analysis of GHG emissions from the Australian light vehicle fleet, Ivankov et al. (2017) describe one third of small passenger vehicle buyers (the lowest emission intensity segment of the passenger vehicles plus LCV market category) purchasing new vehicles that emit 100 g/km as 'optimistic' for the 2025–2030 period. They suggest the requirement for supportive policy measures to achieve lower emissions outcomes, such as incentives for more rapid electrification of the vehicle fleet. Conversely, CCA (2014) has proposed an Australian standard for light vehicles (new passenger cars and LCVs) of 105 g/km at 2025, showing user benefits from this standard well in excess of the costs for achievement. Similarly, US 2025 targets for all new light vehicles (passenger vehicles and LCVs) are 107 g/km (cars 86 g/km; LCVs 129 g/km), consistent with a light vehicle target of ~100 g/km by 2030, or lower. NTC (2016) indicates that the European average emission intensity for *new passenger vehicles* (excluding LCVs) in 2014 was 124 g/km, already below the EU 2015 target of 130 g/km. This 124 g/km emissions rate was 30% lower than the comparable Australian passenger vehicle figure of 177 g/km. The European Union passenger vehicle emissions (legislated) target for 2021 is 95 g/km (147 for LCVs), with targets of 68–78 g/km for 2025 under discussion for passenger vehicles (CCA, 2014). Taking the midpoint of the 2025 range implies a reduction in emissions intensities for new European passenger vehicles of 42% between 2013 and 2025.

The EU 2014 average *new LCV* emission rate was 28% lower than the Australian 2014 rate (NTC, 2016), similar to the differential noted between Australia and the EU for new passenger vehicles (of 30%). The 2020 EU emission rate target for new LCVs is 147 g/km, 36% below the 2015 Australian rate, while the US 2025 LCV target rate is 31% below the US 2017 rate. These figures, together with the differences between LCV emission rates for new vehicles from the same manufacturer sold in Australia, compared to Europe (NTC, 2016), suggests that an emissions reduction improvement rate for LCVs similar to that for passenger vehicles over coming years would not be unreasonable for Australia, as a working assumption. The US improvement rates for cars and LCVs from 2017 to 2025, embedded in the 2025 targets, are very close, supporting this assumption.

Closer alignment of Australian GHG emissions performance with future EU or US emissions standards would go a long way to delivering substantial cuts in Australian light vehicle GHG emissions. To illustrate, a mandatory Australian GHG emissions intensity rate for new passenger and light vehicles of ~107 g/km (cars 86 g/km; LCVs 129 g/km) in 2025, as in the US, would mean an improvement in new vehicle emissions intensity of 56% (from 241 g/km) from a 2005 base at the new vehicle end. Cars and LCVs should be expected to achieve similar rates of improvement, as in the US. Allowing time for diffusion of new vehicles through the fleet mix, this would go a long way to supporting light vehicle emissions reductions exceeding 40% by 2030, against a 2005 base, depending on how VKT evolves but transport policy can influence VKT growth.

There is thus substantial scope for Australia to move to significantly less emissions-intensive passenger/light commercial vehicles quite quickly, provided there is the political courage to drive (mandate) lower new vehicle GHG emissions standards, taking a lead from Europe and the US. A relatively fast move towards electric vehicles (EVs), in particular, would be of great assistance in terms of lowering emissions outcomes. CSIRO (2017) estimate that, with the current electricity generation mix, electric vehicles are already 50–70% less emissions intensive than internal combustion engines in Australia and argue that electric vehicles are essential to widespread emissions reductions in the road transport sector, particularly for light vehicles. However, it also found that electric vehicles are not yet cost competitive. A recent meta-study of take up forecasts by ENA and CSIRO (2017) found that, without significant policy interventions or sharp rises in fuel prices, electric vehicle adoption is likely to remain well below 15% in Australia by 2030. Electric vehicles are, therefore, currently not expected to provide a major contribution in reducing light vehicle emissions intensity before 2030. However, mandatory emissions intensity standards, along the lines suggested above, should help to accelerate the market share of EVs, particularly if announced well ahead of implementation dates and supported by other demand incentives (e.g., preferential sales tax treatment). A move to less emissions-intensive passenger vehicles should be made much easier in political terms by the cessation, in late 2017, of relatively emissions-intensive vehicles being manufactured in Australia.

The contribution that EVs can make to lowering GHG emissions relies partly, of course, on the emissions performance of the recharging system. If electricity is sourced from brown coal, for example, as would currently be most common in Victoria, EV emissions reduction contribution is minimal. Renewable sources, which deliver the best EV emissions contribution, provided only 14% of Australia's electricity in 2015–16 (DIIS, 2016) but this share is growing quite quickly. This underlines the importance of recognising whole-of-lifecycle approaches to assessing emissions reduction performance.

This assessment of potential emissions reductions from improved emissions intensities in the passenger and light vehicle fleet is optimistic. A major risk, however, is that the gains achieved in this area will be swamped by increased vehicle use (VKT). Sections 5–7 discuss behaviour change opportunities to mitigate this risk.

4.2. Freight (heavy vehicle) emissions intensity

Combining motor vehicle VKT data from BITRE and emissions data from DOE (2015), it is apparent that the implied average emissions intensity of Australian rigid and articulated trucks plus buses has remained largely stable between 2002 and 2015 (Mulley et al., 2017). Variation has been up and down by only a few percentage points, with 2015 only about 2% lower than 2002. Analysis for Europe and the US by the International Council on Clean Transportation (Muncrief and Sharpe, 2015; Dalgado and Lutsey, 2015) reaches a similar conclusion for fuel consumption (and, by extension, for GHG emissions) for the major tractor-trailer combination vehicle category, while recognising that tailpipe emissions reduced significantly over this period (a contributory factor to the lack of progress on improving fuel economy). They note a trend to heavier trucks with larger, more powerful engines, as is also happening in Australia.

GHG emissions from heavy vehicles have not received nearly the focus that has been accorded light vehicle emissions. The Obama Administration in the US, however, recognised the importance of achieving heavy vehicle emission reductions if overall GHG targets were to be achieved and introduced Phase 1 and Phase 2 targets, differentiated by vehicle category, to spur emissions reductions. Reviewing the scope and content of those Phase 1 and 2 regulatory requirements, Muncrief and Sharpe (2015, p. 12) conclude that they will ‘result in a 33% reduction in per-vehicle fuel consumption rates in tractor-trailers from a 2010 baseline’. Delgado and Lutsey (2015) note potential for further reductions, suggesting a possible halving of fuel use for tractor-trailers by 2030 with a range of advanced technologies, against the US 2010 outcome. We are also aware of technology currently being tested in trucks to reduce particulate and NO_x emissions, where an associated benefit is substantially lower CO_2 emissions (verified in trials by certified testing). We conclude that a 40% reduction in emissions intensity at the individual Australian heavy vehicle level by 2030 seems a reasonable opportunity, against a 2005 base, provided there is sufficient regulatory push through measures such as mandatory fuel economy standards and urgency therein. Vehicle use then becomes key to total emissions outcomes.

5. Scoping a 40% emissions reduction on 2005 by 2030

5.1. A scenario that meets the target

The analysis thus far has suggested opportunities for substantially cutting Australian road transport GHG emissions by improving emissions intensity outcomes. However, increasing vehicle use has been, and seems likely to continue to be, a challenge. Taking the improvements in emissions intensity discussed in Section 4 as a given, we refreshed the spreadsheet model used in Stanley et al. (2011), to provide a broad sense of the challenge confronting policy with respect to vehicle kilometres of travel, if a 40% GHG reduction target on 2005 emissions is to be achieved by 2030. Fig. 3 details the broad components of a set of outcomes that would deliver the intended 40% emissions reduction. Table 1 identifies the contribution of each outcome area as at 2030 in this scenario.

Table 1 suggests that improvements in emissions intensities, as outlined in Section 4, can deliver almost 60% (29.2 Mt) of the 50 Mt annual emissions reductions that are needed at 2030 to meet the 40% target. Behaviour change measures (with outcomes listed as 1–5 in Table 1) need to provide the remaining 21 Mt. How feasible are the outcomes from the various measures embedded in Table 1? We provide an initial assessment here but the modelling set out in Sections 6 and 7 provides a more robust test of feasibility.

5.2. Built environment influences on VKT

Policy measures to reduce VKT, and to increase active and public transport use, are often grounded in land use transport integration. We consider some of the international evidence in this area and then talk briefly about Australian context.

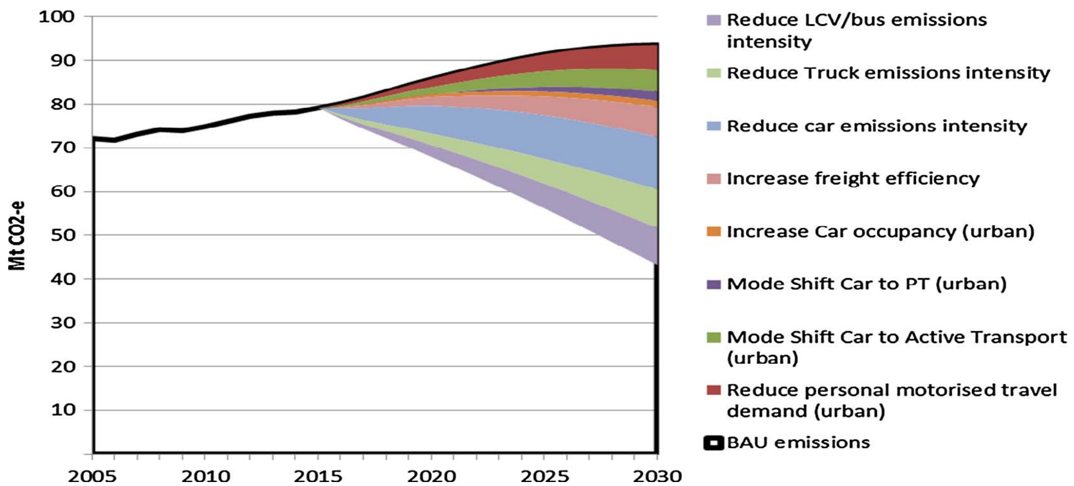

Fig. 3. A scenario for achievement of a 40% cut in Australian road transport GHG emissions: 2005–2030.

Table 1
Policy outcome targets for cutting Australian road transport GHG emissions to 2030.

Policy outcome	2015 level	2030 target	Contribution to emissions reductions against BAU (Mt)
1. Personal travel demand reduction (reduced car VKT)	n.a.	15% reduction	5.8
2. Increase active transport mode share	n.a.	15% shift from car	4.9
3. Increase public transport mode share	9.1%	20% share	2.1
4. Increase car occupancy	1.56	1.67	1.4
5. Improve freight efficiency	n.a.	15% emission reduction	6.9
6. Reduce vehicle emissions intensity			
cars	n.a.	56% below 2005	12.0
light vehicles	n.a.	56% below 2005	7.7
heavy vehicles	n.a.	40% below 2005	9.5
Total target reduction			50.3

The most comprehensive review of connections between the built environment and travel, which underpins much contemporary international thinking about integrated land use transport planning, is the meta-analysis by Ewing and Cervero (2010), who talk about the five 'Ds' of built form in terms of how they impact (in particular) on car travel distances (VKT): density, diversity, design, destination accessibility and distance to transit. Ewing and Cervero report impact elasticities, which show the relative sensitivity of response variables (primarily VKT in their case) to changes in the respective Ds. Most individual reported elasticities are small but the combined effect of a number of measures can be important. This underlines the importance of integrated approaches to land use transport policy and planning, encompassing integrated *regional* and *local* scales of thinking. For example, combined elasticity values for motor vehicle VKT with respect to multiple built-environment variables can total about −0.2 to −0.3. This suggests that having a range of supportive land use transport measures, as embedded in the five Ds, might reduce car use in the applicable area by perhaps 20 to 30 or so per cent over time, given the length of time it takes to change some elements of the built form. US case studies are prominent in the Ewing and Cervero work, so it is also arguable that somewhat greater response elasticities might be found in higher density, more compact, urban settings, although this possibility may not benefit low density Australian cities greatly.

Perhaps the most notable urban land use/transport policy and planning focus on VKT is found in Vancouver, B.C., and in Portland City in Oregon. The Vancouver region's long term metropolitan transport strategy ambitiously targets zero growth in VKT to 2045, with associated contributory targets for (1) 50 per cent of all trips by 2045 to be made by walking, cycling or public transport (the share was 27 per cent in 2011) and (2) the average distance people drive to be reduced by one-third (Translink, nd, 2013). The achievement of these joint targets would deliver benefits in terms of (for example) congestion, greenhouse gas emissions, air quality, road safety and urban containment.

Portland City, Oregon, is also being ambitious on vehicle kilometres of travel. Portland City accounts for over one-quarter of the total metro Portland population. The City is aiming to reduce VKT, against a backdrop where the Oregon State Transportation System Plan is mandating that cities of over one million people (which includes Portland Metro) lower VKT per capita by 10 per cent within 20 years.[2] The State-wide target does not necessarily imply lower VKT in total, since population growth rates may exceed the reduction in per capita emissions, but City of Portland is aiming for such an outcome for its part of the metro area.[3]

In terms of Australian context, the idea of the 20 min neighbourhood, as embedded in *Plan Melbourne* (DPCD, 2014) and its update *Plan Melbourne 2017–2050* (DELWP, 2017), has been framed with the intent of reducing the need to travel and making active and public transport more attractive options. All major Australian cities are seeking to increase active and public transport modal shares. Cities like Melbourne and Perth have achieved strong increases in public transport mode shares over quite short periods of time, by significantly increasing service levels and Sydney, Melbourne and Brisbane are investing large sums in urban rail upgrades at present, to support a growing PT mode share. Sydney is also investing heavily in buses.

We note, however, that achieving only a 10% shift from car to active transport, rather than the 15% included in Table 1, reduces the designated GHG emission savings by around 1.6 Mt, which would need to be offset by additional reductions elsewhere if the 50 Mt target is to be met by 2030. This needs further research but a 10% shift is possibly more realistic, given rates of change that have been achieved by other cities (e.g., several German cities have increased their cycling mode share by 3 percentage points in 6–10 years). Faster rates of reducing vehicle emissions intensity are likely to be the way to take up any such gap in emissions reductions from behavioural change.

This short assessment of international evidence suggests that achieving the *combined* reductions in VKT and increases in active transport and public transport mode shares embedded Table 1 may be somewhat too ambitious *in terms of a 2030 time horizon* but not if a slightly longer time period is chosen. However, a firm policy setting to change the balance between growth in car/light vehicle use and growth in active transport and public transport, while shortening trip lengths, may still see the targets in Table 1 achievable, at a stretch. To test this out, we have undertaken some exploratory modelling of Melbourne and Sydney travel behaviour in Sections 6 and 7.

[2] https://www.portlandoregon.gov/transportation/article/370,492. Viewed 1 November 2017. The Oregon requirement is formally in terms of vehicle miles of travel, in accord with US custom.
[3] http://www.toolsofchange.com/en/case-studies/detail/658. Viewed 1 November 2017.

Table 2
Descriptive Statistical Area Level 2 level data for Melbourne 2011 AM peak travel analysis.

Variable	Units	Mean	Standard deviation	N
Car trips	Number	6921	3415	275
Public transport trips	Number	1013	801	275
Population	Number	14,941	7083	275
Proportion of population aged 5–17	Proportion	.154	.065	275
Population density	Pop/hectare	20.03	15.60	275
Job density	Jobs/hectare	15.33	64.68	275
Average weekly household income	$/household	1612	365	275
Average car travel time (weighted by trips)	Minutes	14.00	2.65	275
Average PT travel time (Inc. walk/wait) (weighted by trips)	Minutes	73.96	17.73	275
Motor vehicles per capita	Number	.585	.103	272[a]

[a] Note: 3 zones are industrial, having no residential population.

In terms of the other components in Table 1, **car occupancy rates** in Australian cities are very low. Modestly lifting these rates by ~0.1 persons while retaining existing occupancy rates in rural areas, would save about 1.4 Mt of GHG emissions. Road pricing reforms are a key opportunity to drive such change.

Freight efficiency (reduced fuel consumption over business as usual) is assumed to be 15% higher than business as usual in 2030 in Table 1, requiring an annual improvement rate of a little less than 1.2%, through measures such as reducing empty running, improved route planning and better aligning vehicles and tasks. Some mode shift to rail is also relevant here. Given the slow rate of productivity improvement in the economy as a whole over the last decade or so (Stopher and Stanley, 2014), this may be a big ask. Again, we see road pricing of heavy vehicle movement a key requirement. If the productivity growth rate was only 0.8% p.a., then the emissions reduction shortfall would be 2.5 Mt, which is significant but not insurmountable in terms of substitution of alternative emissions savings to still aim for a 40% reduction target.

The **emissions intensity** improvement rates embedded in Table 1, from improved fuel efficiency and substitution of less emissions intensive energy sources, and GHG emissions reductions associated therewith, have been argued in Section 4 and are, we believe, quite feasible, given the political will.

6. Prospects for future motor vehicle VKT: a Melbourne case study

To gain a more evidence-based understanding of factors influencing motor vehicle VKT in Australian cities, an exploratory analysis was undertaken on personal morning peak (7–9.00 am) travel in Melbourne, since achieving mode shift in the AM peak from car to public transport, as part of a package of measures to reduce motor vehicle VKT, is likely to deliver the largest co-benefits, such as reductions in congestion, lower accident rates and cleaner air, as well as GHG emissions reductions.

Socio-economic, land use and travel data for the AM peak was made available through the Victorian Government, at SA2 (local area) level. Table 2 shows mean data for a number of variables for 2011. Most of the variables set out in the data have been identified in the preceding discussion as potentially significant influences on modal trip rates. *Population aged 5–17* was included because of the large swing from walking, cycling and PT to car for the (peak) journey to school in Australian capital cities over the past few decades. To reduce problems of multi-collinearity, this variable was expressed instead as *Proportion of population aged 5–17*.

Separate linear multiple regression models were developed for 2011 car and PT trip rates at SA2 level. F tests showed both were significant at the 1% level. Durban-Watson statistics were 1.850 and 1.950 respectively, both supportive of a lack of serial correlation. VIF statistics were all under 3.7 in both models, supporting a lack of multi-collinearity between the independent variables. Adjusted R^2 for the car trips model was 0.941 and 0.843 for the PT trips model, so the various independent variables in each model explain a

Table 3
Model for AM peak car trips generated at SA2 level in Melbourne in 2011.[a]

Model variable	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
(Constant)	1328.027	619.581		2.143	.033
Population	.462	.008	.958	61.124	.000
Proportion of population 5–17	3543.841	926.361	.068	3.826	.000
Population density	−43.731	5.532	−.200	−7.905	.000
Job density	−1.141	.904	−.022	−1.263	.176
Ave HHI	.359	.185	.038	1.942	.010
Av PT travel time	−3.589	5.055	−.019	−.710	.478
Av car travel time	−86.140	21.620	−.067	−3.984	.000
Motor vehicles per capita	−119.940	809.317	−.004	−.148	.882

[a] Note: Dependent variable: car trips.

Table 4
Model for AM peak public transport trips generated at SA2 level in Melbourne in 2011.[a]

Model variable	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
(Constant)	661.490	251.214		2.633	.009
Population	.057	.003	.499	19.646	.000
Proportion of population 5–17	−.238.659	355.228	−.020	−.672	.502
Population density	11.200	2.117	.218	5.291	.000
Job density	4.459	.345	.362	12.943	.000
Ave HHI	.089	.084	.036	1.064	.288
Av PT travel time	−14.391	2.077	−.320	−6.927	.000
Av Car travel time	18.107	8.297	.060	2.182	.030
Motor vehicles per capita	−182.635	319.248	−.023	−0.572	.568

[a] Dependent variable: PT trips.

substantial part of the variation in the respective dependent variables at SA2 level in 2011.

Looking only at the significant independent variables, Table 3 suggests that AM peak car trips at SA2 level increase with population, with the size of the relevant Standardised Beta coefficient suggesting the dominance of car use among the Melbourne population, and also with the proportion of the population aged 5–17 (reflecting the increasing dependence on car for the trip to education in Melbourne) and household income but reduce slightly as population density increases and as car travel times increase.[4] All these significant variables have the expected signs. The motor vehicles per capita variable has an unexpected sign but is not significant. The implied elasticity of car trips with respect to population is 1, suggesting that, other things being equal, doubling population will double car use. The car use model thus reinforces the obvious point that a bigger population implies greater car use, which will, in turn, increase GHG emissions unless positive counter-acting measures are taken.

Table 4 sets out the equivalent model for AM peak public transport trips. In terms of the significant variables, PT trip numbers at SA2 level increase with population, population density, job density, household income and with increasing car travel times but reduce with longer PT travel times. The proportion of the population aged 5–17 and motor vehicle ownership were not significant. The implied population elasticity is 0.85 for PT use, lower than the comparable car elasticity value (1.0).

Calculations of the implied elasticity of AM peak car trips at SA2 level with respect to population density, at mean values of all variables, suggests a value of −0.13 (i.e. doubling SA2 population density will reduce AM peak car trips by about 13%). Conversely, doubling both population and job densities increases projected PT trips by about 30% (implying an elasticity of PT use with respect to combined population and job density of 0.30). The population density contribution is 0.23 and job density 0.07. The elasticity value for car use with respect to population density is not directly comparable with the values cited in Ewing and Cervero (2010), since they focus primarily on motor vehicle VKT rather than trips. They found a weighted average elasticity with respect to household/population density of −0.04 (based on 9 separate study sets of results), compared to the −0.13 elasticity value found for AM peak car trips with respect to population density in the current study. These results are sufficiently close, however, to provide some comfort, recognizing their different origins and scope.

Elasticity values for AM peak transit trips with respect to density, as cited by Ewing and Cervero (2010), are more directly comparable with the PT elasticity found in the current study. They cite weighted average elasticities of 0.07 for household/population density and 0.01 for job density but with a number of individual reviewed studies finding elasticity values of 0.2 or higher with respect to population density alone. The current study's combined AM peak transit elasticity value of 0.30 (population 0.23; job density 0.07) is consistent with the higher values reported in Ewing and Cervero.

The independent variables from Tables 3 and 4 were used to explore the broad implications of the following scenarios:

- Scenario 1: Melbourne's population increases by 1 million people (24.3%), with this increase all happening at 2011 densities and no other independent variables changed. This scenario might be labelled continued urban sprawl.
- Scenario 2: Melbourne's population increases by 1 million people, with all this increase being taken up by population density and job densities increasing at the same rate (24.3%). This is a partial SmartGrowth scenario.
- Scenario 3: As in Scenario 2 but with PT mean travel times reduced by 10 min and car mean travel times increased by 5 min. This is the partial SmartGrowth scenario backed up by transport policy to achieve mode shift from car to PT, making it a SmarterGrowth scenario.

The projected effect of these scenarios on AM peak car and PT trip numbers for the typical SA2 are set out in Table 5. The scenarios show the way future population growth tends to increase demand for car travel, even if the projected car mode share declines marginally, as in Scenarios 2 and 3. This effect is strongest in Scenario 1, the urban sprawl scenario. Increasing densities reduces the rate of growth in car use, as shown by the differences between scenarios 1 and 2. Improving PT travel speeds and allowing car speeds to continue to decline, as they have been doing for over a decade in Melbourne, is where the largest relative gains in PT use

[4] Car travel times were initially derived from modeled network skims.

Table 5
Testing future scenarios and their effect on AM peak car and PT trip rates at SA2 level.

Scenario	Modelled SA2 car trips (motorised mode share)	Modelled SA2 PT trips (motorised mode share)
2011 base case	6921 (87.3%)	1009 (12.3%)
Scenario 1	8731 (87.8%)	1209 (12.2%)
Scenario 2	8515 (86.9%)	1281 (13.1%)
Scenario 3	8047 (84.1%)	1515 (15.9%)

are achieved but that scenario (3) still projects 16% more car trips than in 2011 for the typical SA2 in a bigger Melbourne. PT use is projected to be 50% higher under this scenario than in the 2011 base case, but this is not as high as embedded in the 40% reduction scenario set out in Table 1. Table 5 suggests the need for more substantive imposts on car use and greater encouragement to PT, if car VKT is to be contained (in this case for the AM peak).

7. A Sydney case study

There are a large number of potential policy measures that could be used to induce a reduction in car VKT and a corresponding increase in public transport and active travel mode shares, to contribute to meeting the posited emissions reduction targets. In this section, to explore some of these potential policies and identify their likely effects, we use the MetroScan-TI model system for Sydney. This system incorporates choice models for a full set of household, individual and firm decisions that are associated with transport and land-use, including longer term decisions about where households choose to live and work and how they travel (Ho and Hensher, 2016). Of particular use to the current paper is that all these decisions are endogenous and so do not impose exogenous assumptions that may limit what choices are made. This means that increases in the cost of using a car will not necessarily result in higher public transport use, if households are able to adjust in other ways (e.g., by reducing the number of leisure trips or re-locating). The full set of models available in the MetroScan-TI model system is shown in Fig. 4.

To illustrate how a range of policy measures might be used to reduce car VKT, we look at a variety of policies for Sydney, focusing on those that may encourage switching from car to alternative modes but without substantial changes to infrastructure, beyond those that are already committed (i.e., City and South East Light Rail, new Metro lines, etc.). Forecast mode share and car VKT are provided for 2030 and compared to a base scenario for 2030 that assumes policies existing today will remain unchanged. The policy changes that were modelled, sometimes in combination, were:

- an increase in fuel prices (by increase in excise), by 7.5%, 12.5% and 25% (the current tax rate is about 40c/L),
- a reduction in public transport fares of 25% and 50%,
- high frequency public transport services (double current frequencies),

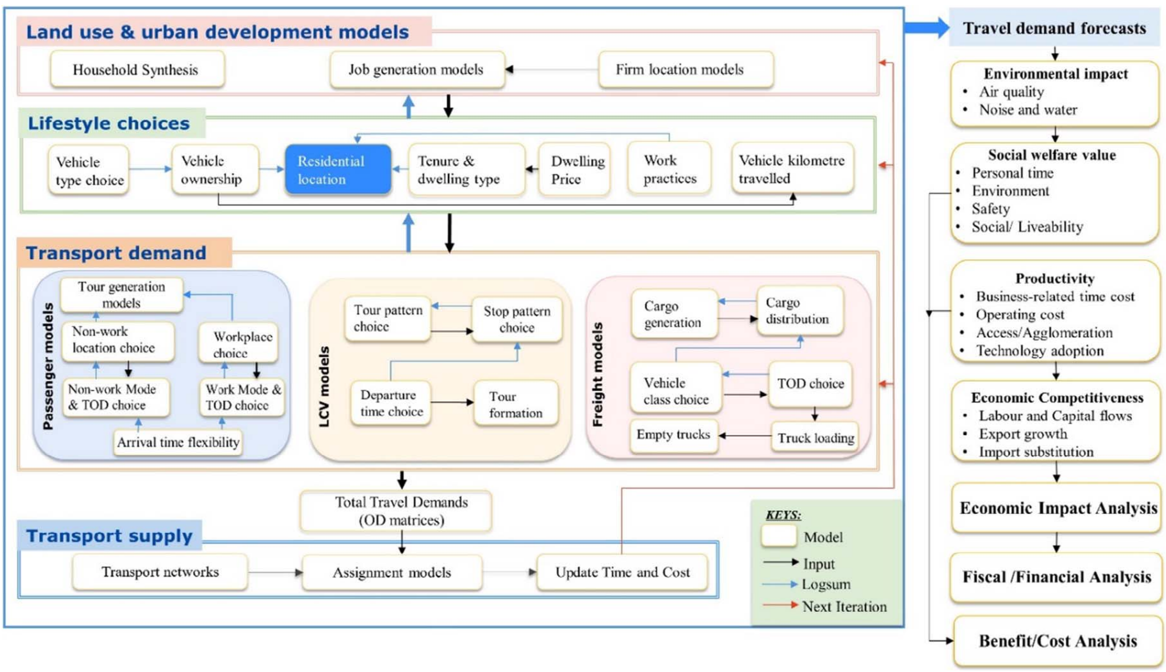

Fig. 4. MetroScan-TI model framework.

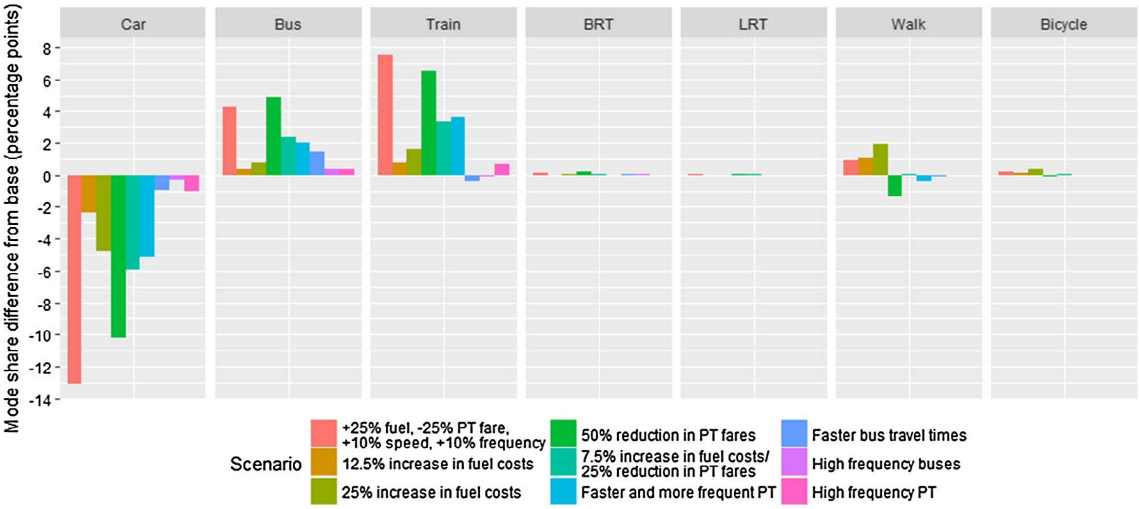

Fig. 5. Change in mode share from base, in 2030.

- faster public transport (20% faster than current speeds).

The base mode shares are 76.7% for car travel, 8.6% for public transport and 14.7% for active travel (primarily walking). The changes in mode share and numbers of trips for each scenario respectively, shown in Figs. 5 and 6, indicate that policies that measurably change the costs of travel have a larger effect on shifting people from using cars to public transport than changes in service levels, given the range of service level changes that were considered. Of interest is that, at least in terms of mode share, a substantial reduction in public transport fares has a larger effect on mode share than other policies, significantly reducing car use and increasing public transport use. In part this can be attributed to relocation and vehicle ownership decisions, that increase the behavioural response elasticities compared to the short-run, when these decisions are often fixed. A decade of sustained higher costs of driving relative to public transport provide for greater opportunities (and incentives) for making longer term decisions to reduce transport costs. This policy also has an inducement effect, generating an extra 7500 trips per day. A combination of "sticks" (i.e., higher fuel taxes/excise) and "carrots" (i.e., lower public transport fares) appears to be more effective than only increasing the cost of using a car. When used in isolation, more service oriented policies do not appear to have as large an effect at an aggregate level, although stronger localised effects are apparent in areas well serviced by public transport. Several linked improvements to public transport services, such as both reducing travel times and improving frequencies, do appear to have a much greater effect on reducing car travel, to a level more comparable to policies that increase the costs of car travel.

Active transport (walking and cycling) changes relatively little in terms of mode share from the policies tested, although the package of initiatives does not include specific investment initiatives to promote uptake (e.g., exclusive cycling lanes), due to a lack of local empirical evidence to support behavioural responses in cities like Sydney. In terms of measures included, the effect is greatest

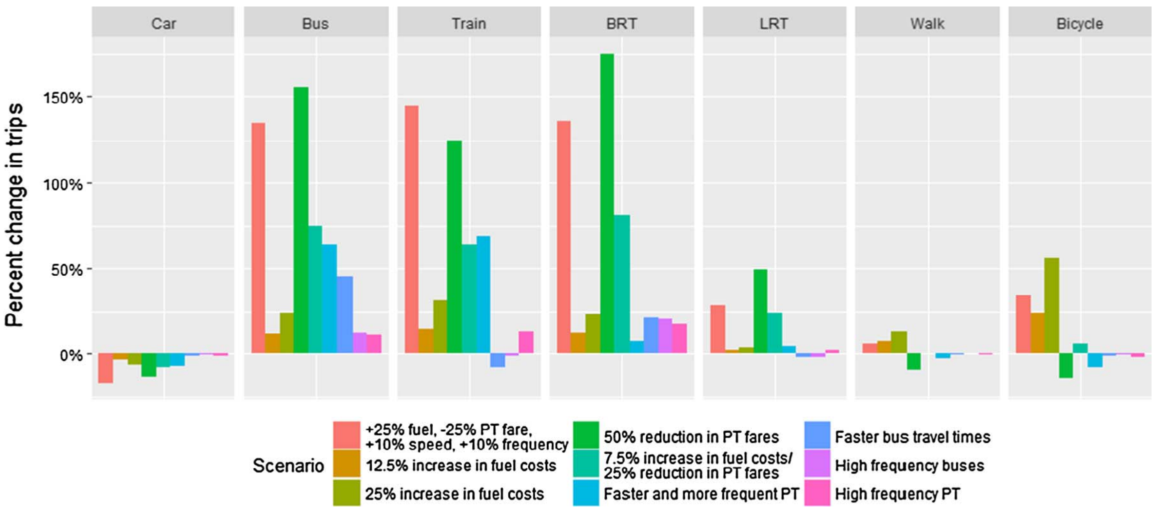

Fig. 6. Percent change in trips from base, in 2030.

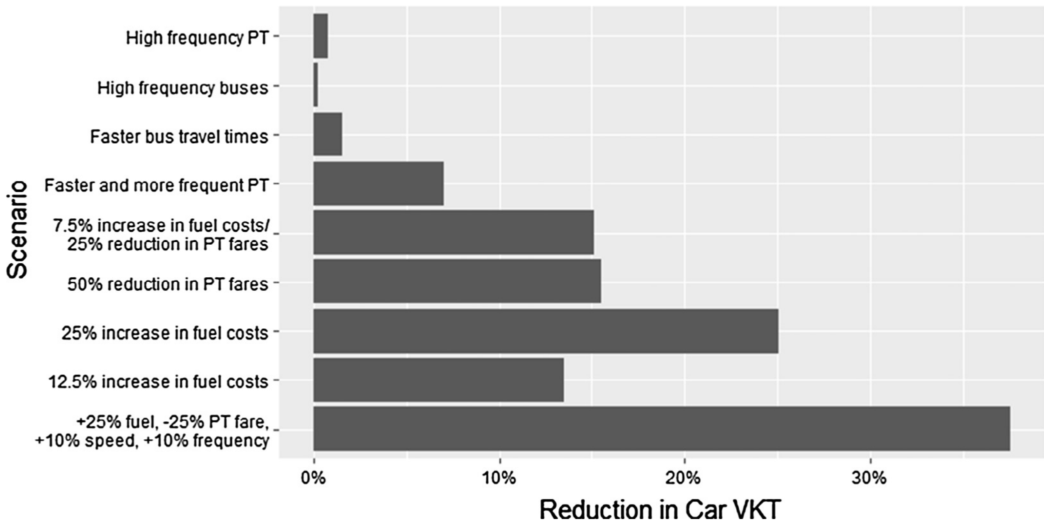

Fig. 7. Reduction in VKT.

for policies that reduce the attractiveness of the car. The small initial mode share of cycling means that the effects of policy changes on mode share are not as apparent as for walking. However, when compared to the initial number of trips, the policy that increases fuel costs by 25% results in a 56% increase in bicycle trips compared to the initial levels, although the effect is smaller for other policies. The mode share of active transport (as the main mode) decreases when public transport fares are reduced, because of a switch from walking and cycling to public transport. This is consistent with findings by Ellison et al. (2017) on Sydney's Opal card that found that the availability of the Opal card resulted in a reduction in walking as the main mode, because public transport became more convenient and, in many cases, cheaper.

Changes to mode shares, as well as to the total number of trips, are important but do not necessarily reflect the likely change in emissions. This is because, although in the short term there may be a shift towards public transport or active travel, in the longer term households can make additional changes, including what vehicles they own, where they live and where they travel to for work and other purposes. As a result, the change in car VKT (and ultimately emissions) may be either lower or higher than the change in the number of trips, as people choose to travel shorter or further distances. Fig. 7 shows the percent reduction in VKT from each policy. What this shows is that, although increasing fuel costs by 25% results in a reduction in car *trips* of only six percent, this policy has a substantially greater effect on *VKT,* with a reduction of approximately 25%. In contrast, changes to public transport (either fares or service) have a relatively smaller effect on car VKT than in the number of trips. This is because, although some individuals may choose to switch to public transport (or active travel) as a consequence of high costs of driving, some individuals may not be able or willing to switch but can still make changes to where they travel to, shortening car trip lengths (as in measure 1 in Table 1).

Fig. 7 indicates that a number of combinations of policy measures can reduce car and light vehicle VKT by around 15%, and some combinations can deliver 25–30 + % reductions, against base expectations at 2030. The higher end of this range is consistent with the behaviour change measures embedded in the scenario laid out in Table 1, with increased public transport mode shares/trips and shorter car trips accounting for most of the reduction in VKT. Somewhat surprisingly, and reflecting the value of integrated modelling with MetroScan-TI, these policy measures tend to rely more on higher fuel tax rates and lower public transport fares than on major changes in public transport service levels. However, one consequence of the reduction in car/light vehicle VKT and increase in PT use is a requirement to invest in improved PT services, to accommodate the higher loads.

8. Discussion and conclusions

The preceding analysis suggests that a concerted policy intention to reduce Australia's road transport GHG emissions by 40% on 2005 levels by 2030 has some prospect of success but only if the policy intention is supported by a comprehensive and integrated set of actions to deliver on that policy intent. These actions must include both measures to reduce the emissions intensity of the vehicle fleet and measures to change behaviour towards increased use of low emissions modes of transport, encompassing a full range of land use transport policy and planning initiatives and measures to drive culture change towards less emissions intensive travel behaviours.

Mandatory emissions standards are the single most important requirement, taking a lead from Europe and the US in terms of standards for the coming decade. Our analysis suggests that a mandatory Australian GHG emissions intensity rate for new passenger and light commercial vehicles of ~107 g/km (cars 86 g/km; LCVs 129 g/km) in 2025, as in the US, and sustained reductions in emissions intensities through the decade, would mean an improvement in new vehicle emissions intensity of around 56% (from 241 g/km) from a 2005 base at the new vehicle end, supporting emissions reductions across the fleet exceeding 40%. Accelerated use of electric vehicles, powered by renewable energy, would support this outcome and mandatory emissions standards should encourage their use. Mandated emissions targets for heavy vehicles would probably aim for smaller reductions in emissions intensities, with

40% by 2030 seeming a reasonable benchmark.

In terms of behavior change, increasing fuel tax by 25%, in line with the corrective fuel tax required to offset the unpriced external costs of road use (Stanley and Hensher, 2017), would drive significant reductions in greenhouse gas emissions. Such a pricing reform would encourage mode shift away from cars to PT and active transport, shorten trip lengths and accelerate take-up of low emissions vehicles, which could be expected to have a lower charging rate because of their cleaner emissions profiles. The higher fuel tax would also provide a revenue stream that can assist in upgrading public transport service levels. Such a pricing reform is likely to take five or so years to deliver.

The analysis also suggests a role for lower public transport fares and improved service levels, to complement higher fuel taxes. The analysis for Sydney suggests that 15–30% reductions in car/light vehicle VKT against business-as-usual is achievable by 2030 with a suitable combination of these measures, higher fuel taxes being particularly important. Relative reductions in VKT in smaller Australian cities (than Sydney) would possibly be smaller, because of less comprehensive PT networks, and would certainly be less in regional areas. Nonetheless, the support that policy measures to encourage behavior change can provide to measures that improve emissions intensity should be sufficient, in total, to make a 40% GHG emissions reduction target feasible, given the political will. Examination of the wider benefits and costs of achieving this road transport emissions reduction should, of course, be part of a broader assessment of the merits of the policies proposed in this paper.

More broadly, to reduce greenhouse gas emissions, land use planning in Australia's cities needs to increase the priority accorded to urban infill, substantially increasing development densities on the urban fringe, orienting development patterns to support the emergence of a small number of knowledge-based suburban clusters, and 20 min neighbourhoods across the whole city. The Sydney analysis in Section 6 did not include potential impacts of policy measures that might accelerate increases in density in that city, which is already Australia's most dense city, although the Melbourne analysis in Section 5 suggested opportunities in this regard. The MetroScan model for Sydney suggests elasticities of VKT with respect to density (population plus jobs) of -0.08, which is similar to the Melbourne value for car trips reported in Section 5 (-0.13) and to values recently reported by Duranton and Turner (2017) for the US for VKT (-0.07 to -0.10). Adding land use policy and planning impetus to the operational and pricing measures assessed for Sydney would thus further increase the opportunities for substantially lowering future VKT in that city.

At the same time, increased priority for a larger mode share for active transport and public transport is required. However, our Section 7 MetroScan analysis for Sydney did not attempt to model behavioural responses to step changes in cycling infrastructure provision, because the current cycling mode share in Sydney is very low. We believe that response elasticities will be stronger than implied by current elasticities if major facility improvements (e.g., networks of cycle paths) were to be implemented. This is an area requiring further research.

The significant and increasing dependence on urban private toll-road initiatives in the largest cities is a challenge that needs to be overcome in pursuing increased mode shares for active travel and public transport. Setting high mode share targets for these modes, as Vancouver has done, and supporting this with plans to deliver on those targets, is a transparent and accountable way to approach this mode switch challenge. A target of around over 40% of city trips in 2030 to be by active or public transport would be a good start, supported by targeted land use/active transport measures and generating benefits of lower congestion, a lower road toll, cleaner air and improved health, as well as lower GHG emissions.

Acknowledgements

The authors thank the anonymous referees for their helpful comments.

The MetroScan-TI project makes use of The University of Sydney's high performance computing service, Artemis. This paper contributes to the research program of the Volvo Research and Education Foundation Bus Rapid Transit Centre of Excellence. We acknowledge the Foundation for partial funding support.

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